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# Comparison of Two Alternative Movement Algorithms for Agent Based Distillations

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**Defence Science and Technology Organisation**

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**ABSTRACT**

This paper examines two movement algorithm options available to the user in the MANA (Map Aware Non-Uniform Automata) agent based distillation. The default Stephen algorithm is compared with nine variations of the alternative Gill algorithm and tested over six different scenarios.

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# Comparison of Two Alternative Movement Algorithms for Agent Based Distillations

## Executive Summary

This paper examines two movement algorithm options available to the user in the MANA (Map Aware Non-Uniform Automata) agent based distillation (ABD). This study follows earlier work completed by Gill and Grieger which proposed an alternative movement algorithm. The aim of this paper is to identify any significant changes in the outcome of a scenario when different movement algorithms are applied.

The default Stephen algorithm is compared with nine variations of the alternative Gill algorithm and tested over six different scenarios. The results tend to suggest that the user needs to take care when constructing a scenario to ensure that the combination of the selected movement algorithm and user defined personality parameters cause the effect intended by the user. The results also suggest that users of ABDs should strongly consider sensitivity analyses of the various movement algorithms as a part of the overall analysis process. The limitations of both algorithms are discussed.

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*Dion Grieger worked in LOD in 2001 as an Industry Based Learning Student. In 2002 he completed a Bachelor of Science (Mathematical and Computer Sciences) majoring in Applied Mathematics. He joined Land Operations Division in December 2002 and is now working in the Concept Studies and Analysis discipline. His current areas of research relate to primarily to counter-terrorism but also to crowd behaviour and control, non-lethal weapons and agent-based distillations.*

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# 1. Introduction

This paper examines two movement algorithm options available to the user in the MANA (Map Aware Non-Uniform Automata) Version 3.0.16 agent based distillation (ABD). This study follows earlier work completed by Gill and Grieger which proposed an alternative movement algorithm. Whilst some comparisons between algorithms have already been made [1] this paper aims to add rigour to those results by conducting investigations using alternative scenarios.

## 1.1 Background

ABDs are low-resolution simulations used principally to explore land warfare operations, though potentially having a wider role that includes the air and maritime environments. Project Albert [2] is a United States Marine Corps (USMC) research effort attempting to integrate the application of ABDs with conventional wargames and simulations, by addressing areas (such as morale, discipline and training; and multi-dimensional (and changing) parameter landscapes) in which the conventional models perform poorly.

The User's Manual of MANA [3] states that 'the most important action of an agent is to move.' This appears justified since being deliberately low-resolution means that the detailed physics of combat are largely ignored (or abstracted to simple constructs) and thus any interesting behaviour should appear as a result of the manoeuvring of the agents about the battlefield which is a result of agent interactions. Movement of agents within the MANA ABD is based on a simple attraction-repulsion weighting system and an associated numerical penalty function. From its current location, an agent moves to the location within its movement range that incurs the least penalty. That is, the agent attempts to satisfy its desire to move closer to or further away from other agents and other battlefield objects (such as terrain, waypoints or goals). This algorithm is applied to each agent on both sides and each is moved to its new location. This process is repeated for each time step in the simulation.

The default 'Stephen' movement algorithm, or penalty function, for MANA is shown below in equation (1). Equation (2) is the alternative algorithm proposed by Gill and Grieger [4]. For simplicity, both of these equations are for the case of a blue agent with no weightings towards other blue agents. Note that if no red agents are detected (R=0) then the first part of each equation is zero. The variables used are defined in Table 1.

$$Z_{new} = \left(\frac{W_R}{100 * R}\right)\left(\sum_{i=1}^{R}\frac{D_{i,new}+\left(100-D_{i,old}\right)}{100}\right)+\left(\frac{W_F}{100}\right)\left(\frac{D_{F,new}+\left(100-D_{F,old}\right)}{100}\right) \tag{1}$$

$$Z_{new} = \left(\frac{W_R}{R^{\alpha}}\right)\sum_{i=1}^{R}\left(\frac{D_{i,new}-D_{i,old}}{D_{i,old}}\right)^{r} + W_F\left(\frac{D_{F,new}-D_{F,old}}{D_{F,old}}\right)^{r} \tag{2}$$

*Table 1 Explanation of Variables*

| Variable | Definition |
|---|---|
| $Z_{new}$ | The penalty for moving to a new location |
| R | Number of red agents within sensor range |
| $W_R$ | Weighting towards red agents |
| $D_{i,new}$ | Distance to the *i*th red agent from the new location |
| $D_{i,old}$ | Distance to the *i*th red agent from the current (old) location |
| $W_F$ | Weighting towards the flag |
| $D_{F,new}$ | Distance to the flag from the new location |
| $D_{F,old}$ | Distance to the flag from the current (old) location |
| r | User defined non-negative variable |
| $\alpha$ | User defined non-negative variable between zero and one |

Whilst it is not the intention to discuss the differences between the two algorithms in detail in this report, two important factors should be noted. The first is that the MANA algorithm treats all agents as if they were 100 units away. This means that the penalty function for moving towards a red that is 5 units away will be the same as that for moving towards a red that is 50 units away. Secondly, the MANA algorithm effectively does not cumulate weightings for each agent detected, that is, a blue agent will have the same penalty for moving towards one red agent, as it will for moving towards 50 red agents. The alternative movement algorithm allows the user to incorporate both the distance between agents, and the number of agents detected, into the movement algorithm via variables r and $\alpha$ respectively. It should be noted that the alternative movement algorithm was only proposed after some counter-intuitive behaviour was noticed in MANA. This paper does not intend to suggest that the MANA algorithm is incorrect, only that it is important that the user fully understands how the algorithm implements the weighting parameters that the user inputs.

# 2. Scenario Construction

Six scenarios were constructed to test the two alternative movement algorithms. In all scenarios the aim of the blue force is to reach their objective (the flag) and at the same time avoid red agents. Red agents can fire at blue agents but, in order to ensure that blue agents are in fact trying to avoid red agents, blue agents cannot fire at red. The starting positions for both teams are the same for all scenarios and are shown in Figure 1.

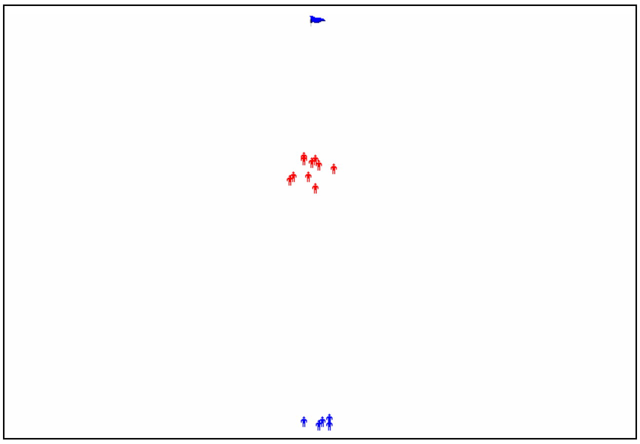

*Figure 1 Starting Positions for Red and Blue*

Each scenario contains either a different force mix (via the number of red agents) or a different repulsion weighting of blue agents away from red agents. The six scenarios have been named 1A, 1B, 2A, 2B, 3A and 3B and are described below.

1. Five blue agents against two red agents
2. Five blue agents against five red agents
3. Five blue agents against ten red agents

In all 'A' scenarios blue only has weightings of positive 100 towards the flag and minus 100 towards red. In 'B' scenarios blue only has weightings of positive 100 towards the flag and minus 50 towards red. All parameters used in the scenarios are summarised in Table 2.

*Table 2 List of Parameters*

| Parameter | Red | Blue |
|---|---|---|
| **Sensor Range** | 30 | 30 |
| **Weapon Range** | 20 | N/A |
| **Probability of Hit** | 0.05 | N/A |
| **Weighting Toward Red** | 0 | -100 (for 'A' scenarios)<br>-50 (for 'B' scenarios) |
| **Weighting Toward Blue** | 100 | 0 |
| **Weighting Toward Own Flag** | 0 | 100 |
| **Movement Speed** | 100 | 100 |
| **Number of Agents** | 2 (for Scenario 1)<br>5 (for Scenario 2)<br>10 (for Scenario 3) | 5 |

To test the alternative movement algorithm the same three values of $\alpha$ (0.01, 0.5 and 1) and r (0.5, 1 and 2) were used as in the initial experiments by Gill and Grieger [4], giving a total of nine alternative movement algorithms plus the default 'Stephen' algorithm. For each algorithm the 'Move Precision' variable was set to one so that only the 'best' move was chosen every time. This gave a total of 60 different scenarios (six scenarios each with ten different movement algorithms) each of which was run for 600 iterations[1]. Each run was terminated when one of the following conditions was met:

[1] This has been shown to be a sufficient number to obtain a reliable mean result in MANA [5].

1. All five blue agents have been shot
2. Any blue agent reaches the flag
3. 500 time steps have elapsed

The statistics collected by MANA from these runs are the number of time steps in the run, the number of casualties from the blue side and whether or not any blue agent reached the flag.

# 3. Results

The results for all 60 scenarios are listed in Appendix A. The results have been tabulated into nine different categories as explained below:

1. Average time to reach the flag (where applicable)
2. Average time over all runs
3. Average time when five blue losses occur
4. Percentage of runs where blue reached the flag
5. Percentage of runs where five blue losses occur
6. Percentage of runs that timed out (reached 500 time steps)
7. Average number of blue casualties for runs where blue reached the flag (where applicable)
8. Average number of blue casualties over all runs
9. Average number of blue casualties for runs that timed out (where applicable)

All values shown represent the average result over the applicable number of runs. Results of particular interest and significance have been selected and presented in this section. Figure 2 shows the average number of time steps for each scenario. The first significant point to note is that variations in the alpha variable of the alternative movement algorithm have almost no effect on the average time taken for each scenario. This is consistent with the findings of Gill and Shi [1]. Of the nine alternative movement options there are three distinct groupings, one for each different value of r. This trend is consistent across all measures of effectiveness used in this study and, as such, further results from the alternative movement algorithm will be grouped into three groups: r=0.5, r=1 and r=2, and will use the average value of all 1800 applicable runs. It is also interesting to note that as r decreases the average time taken also decreases but is never lower than that of the default algorithm. This behaviour highlights the fact that the alternative algorithm, in fact, behaves more like the default algorithm when r tends to zero, that is, the distance between agents is ignored in the penalty calculation. The oscillating behaviour of the r=0.5 case highlights a sensitive region where the differences in weightings in scenario A and B has a significant impact in the overall decision for an agent to either move forward, or retreat. This set of results also appears to be consistent with the findings by Gill and Shi [1] that the default algorithm does not appear to give the agents ‘time’ to react and retreat after detecting red agents. This is supported by Figure 3 which shows that the alternative algorithm produced longer runs far more regularly than the default algorithm. Visual inspection of individual runs suggests that, by taking into account the distance between agents (using the r variable), the alternative movement algorithm seems to allow agents both to advance when safe and retreat when necessary.

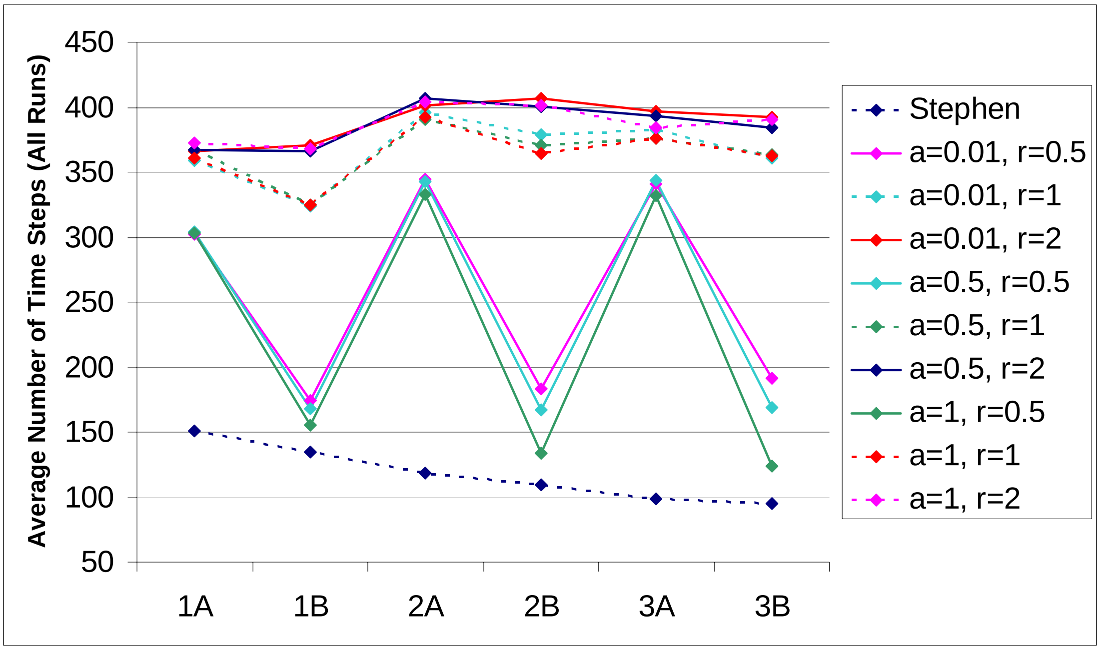


*Figure 2 Average Number of Time Steps*

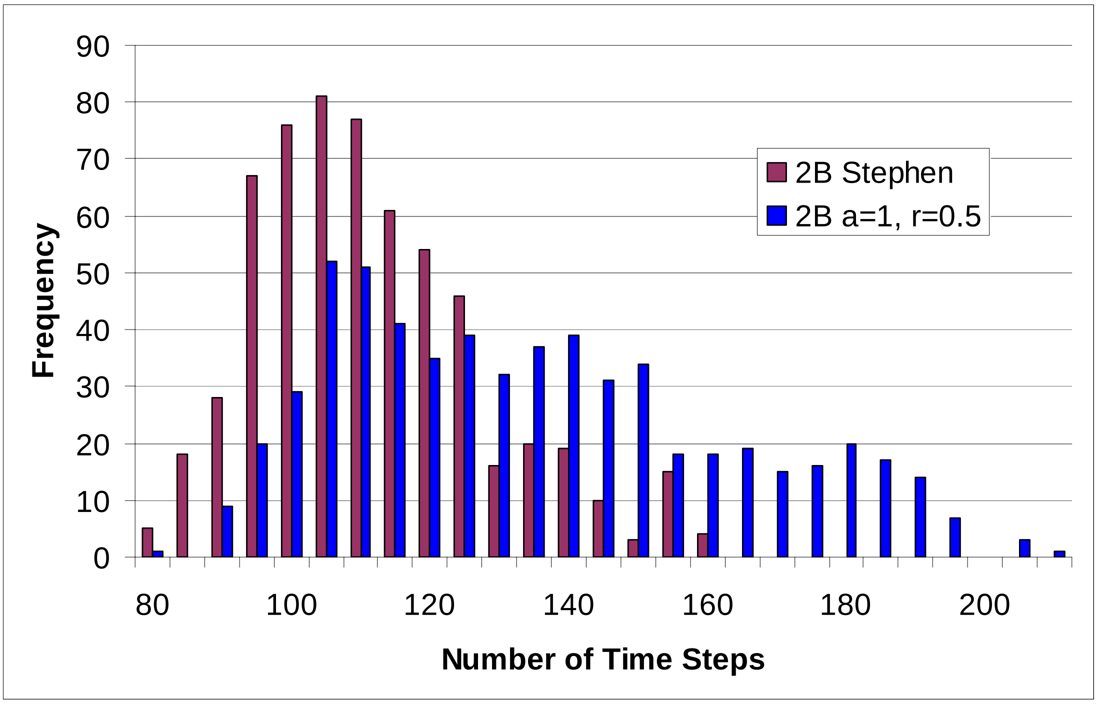


*Figure 3 Distribution Comparisons*

Figure 4 shows the percentages of runs in which blue successfully reaches the flag. It can be seen that blue are not very successful at achieving their objective for scenarios 2 and 3. However, in both scenarios 1A and 1B, blue consistently reach the flag twice as often when the alternative movement algorithm is applied as opposed to the default algorithm. These results should also be considered in conjunction with Figure 5, which shows the average time taken for blue agents to reach the flag. It can be seen that whilst the default algorithm does not allow blue agents to reach the flag as often as for the alternative algorithms, it does generally allow them to reach the flag much faster. It should be noted that, because not all runs were applicable, some data points in Figure 5 represent as few as 13 iterations. However, the results are still significant when compared to the default algorithm. For example, the data point derived from the fewest iterations (r=2, 2A) had a standard deviation of 57 and a minimum time of 336, which is still significantly different to the average of the default algorithm.

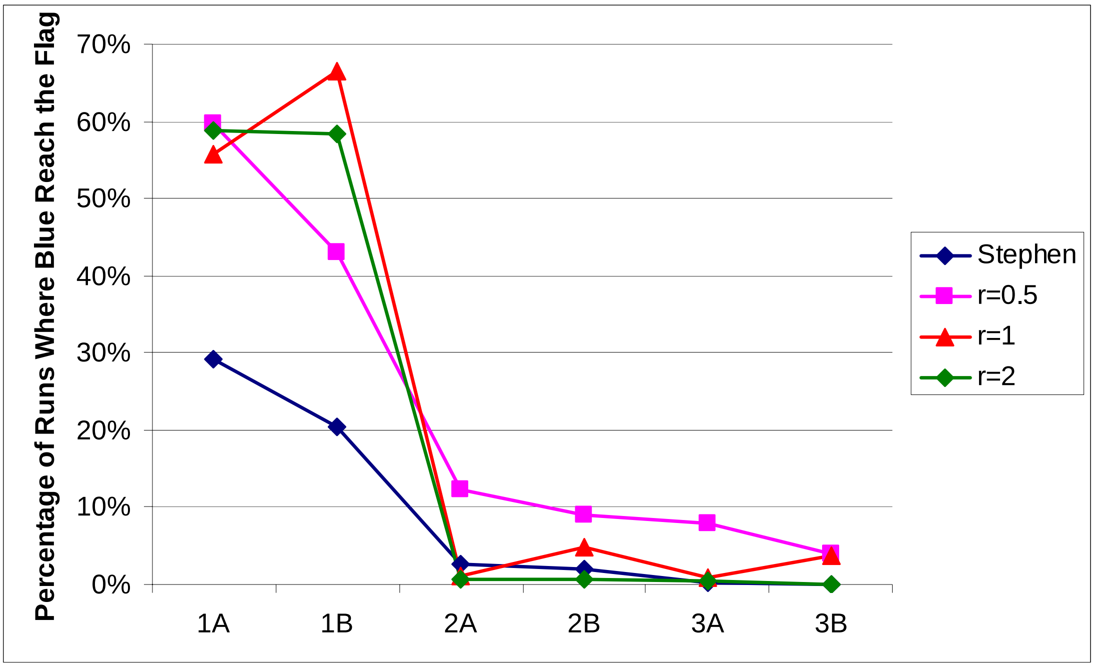


*Figure 4 Percentages of Runs Where Blue Reach the Flag*

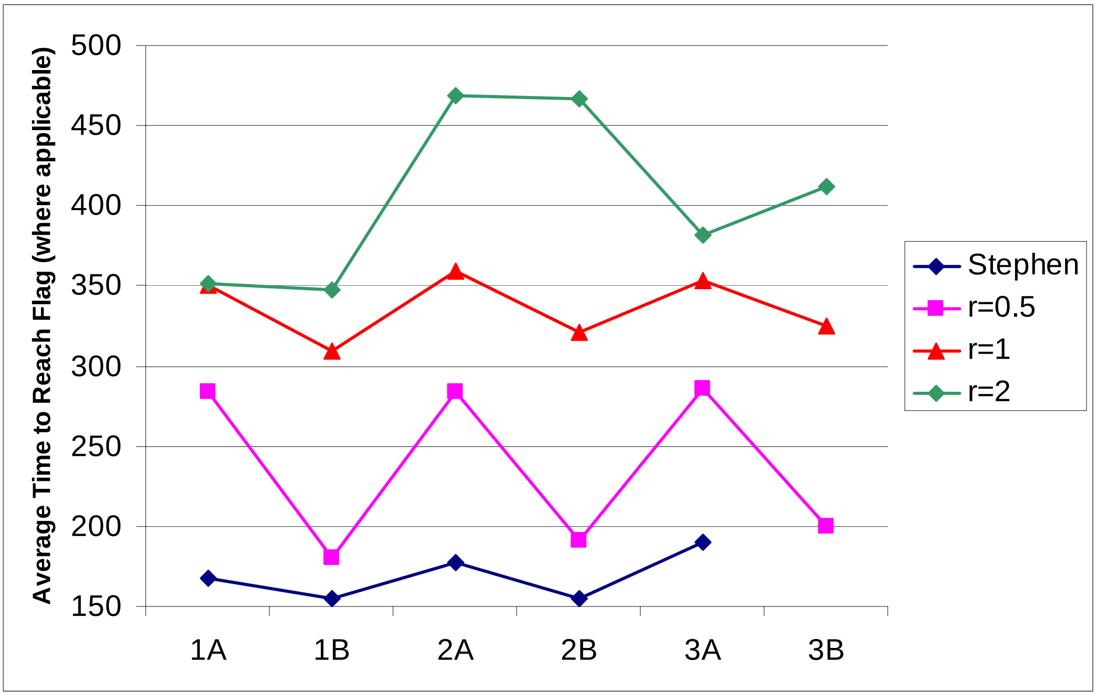


*Figure 5 Average Time To Reach Flag*

Whilst the default algorithm does allow agents to reach the goal faster, there is an additional trade off as a result. Figure 6 shows the average number of blue casualties over all runs. It is clear that all scenarios using the default algorithm suffer more casualties than for any of the corresponding alternative algorithms. Again, this result may suggest that, in these instances, the default scenario does not allow the blue agents 'time' to manoeuvre appropriately to avoid confrontations with the red agents as perhaps intended upon construction of the scenario.

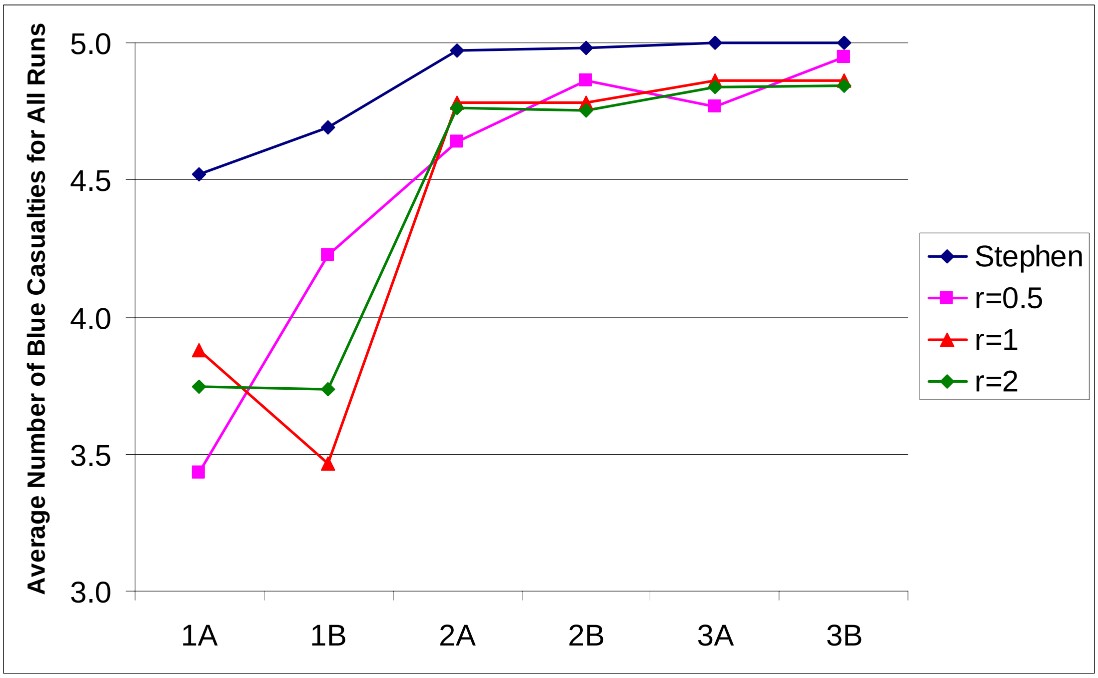


*Figure 6 Average Numbers of Casualties*

# 4. Discussion

As stated earlier, it is not the intent of the author to suggest that the default MANA algorithm is incorrect, only that in some instances it appears to yield results that differ from the interpretation and intent of the user. This has been highlighted by some worked examples of counter intuitive behaviour in an earlier paper [4]. The results presented in this paper do not suggest that any one algorithm is superior, however, they do clearly show that, for the set of scenarios studied, there are clear differences in the outcome of a scenario depending on what movement algorithm is applied. This is not to say that this will be the case for all scenarios, in fact, it is likely that the outcome of many scenarios will not depend on the movement algorithm. As a result, it is important for the user to conduct appropriate sensitivity analyses of the movement algorithm where there is any doubt about the impact that the movement algorithm may have on a particular scenario.

It should also be noted that the results presented in this paper are only for scenarios where there has been no weightings assigned towards friendly agents. For some scenarios it may be desirable for friendly agents to be attracted to each other in order to remain close for support. Using the alternative movement algorithm may introduce unwanted problems for these types of scenarios. This is because any algorithm that gives a stronger weighting to those agents that are close (ie, the friendly agents) will tend to ignore enemy agents and the flag as they are likely to be significantly further away. In fact for all scenarios studied in this report, when a weighting of +50 towards friendly agents was applied to all blue agents there was no movement of any blue agents towards the flag due to the reason mentioned above. A possible solution to this problem would be to only apply the movement weighting towards friendly agents if the agents are not already close to each other. MANA appears to have this facility for all waypoint and agent weightings except, rather inexplicably, for weightings towards uninjured friendly agents. Figure 7 shows a portion of the 'Edit Personalities' section in MANA. The 'Min App.' column is the minimum application distance and disables the personality weighting if the agent is within the designated distance (default zero) of the weighted agent. If this option was also available to uninjured friends the problem described above could be addressed. It should be noted that initial tests conducted by the author using the 'Min App.' option with other agent types have indicated that there may some coding problems with this variable. The option appears to work as described for the waypoints but not for agents.

When the flag becomes insignificant in some scenarios due to its relative distance from the other agents, Gill and Grieger [6] proposed four different components for the alternative movement algorithm to help deal with this problem. Unfortunately only the default case is currently coded into MANA so no comparisons can be made for the scenarios presented in this report. However, the alternative flag components do not deal with the problem discussed above of weightings to friendly agents.

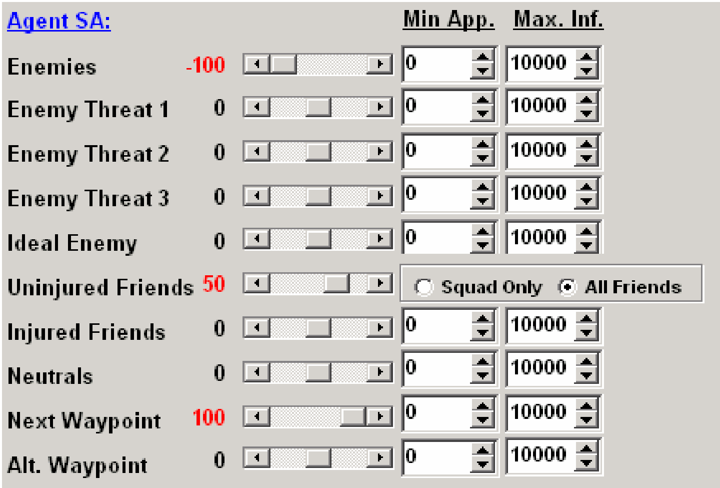


*Figure 7 Portion of MANA Personality Screen*

The results presented in this paper highlight the need for ABD users to take care with both the construction and analysis of scenarios. The author believes that if this is undertaken and ABDs are used as a preliminary modelling and scoping tool, as opposed to a stand alone tool, then they will continue to be a useful modelling technique within the scientific community.

# 5. References

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6. Gill A, Grieger D, Validation Of Agent Based Distillation Movement Algorithms, DSTO-TN-0476, 2003.

# Appendix A: Results Tables

The following tables show the results for all scenarios and for nine different measures of effectiveness. The numbers shown are the average over the applicable number of runs. Typical standard deviations are less than 1% for time step data and less than 0.5% for casualty data. Note that these standard deviations are typical for results where more than 300 runs (50% of total runs for each data point) were applicable. Hence, results where less than 50% of the runs are applicable should be treated with caution. As noted in Section 3 however, these results are still significant when compared to the results from the default algorithm.

*Table 3 Average Time to Reach Flag (where applicable)*

| | 1A | 1B | 2A | 2B | 3A | 3B |
|---|---|---|---|---|---|---|
| **Stephen** | 167.5 | 154.8 | 176.9 | 154.7 | 190.0 | N/A |
| **a=0.01, r=0.5** | 284.0 | 191.0 | 292.0 | 200.4 | 281.6 | 207.7 |
| **a=0.01, r=1** | 346.4 | 305.2 | 358.4 | 331.6 | 328.3 | 326.5 |
| **a=0.01, r=2** | 353.1 | 350.4 | 470.7 | 479.6 | 441.9 | N/A |
| **a=0.5, r=0.5** | 284.8 | 180.1 | 283.5 | 195.1 | 297.1 | 202.8 |
| **a=0.5, r=1** | 353.8 | 314.8 | 373.5 | 309.1 | 337.1 | 333.8 |
| **a=0.5, r=2** | 349.6 | 346.3 | 444.8 | 431.0 | 322.0 | 412.0 |
| **a=1, r=0.5** | 284.0 | 171.2 | 275.9 | 178.6 | 278.1 | 188.6 |
| **a=1, r=1** | 351.3 | 308.8 | 345.7 | 322.5 | 393.5 | 313.8 |
| **a=1, r=2** | 352.7 | 346.4 | 489.5 | 489.0 | N/A | N/A |

*Table 4 Average Time All Runs*

| | 1A | 1B | 2A | 2B | 3A | 3B |
|---|---|---|---|---|---|---|
| **Stephen** | 150.6 | 135.1 | 118.9 | 109.6 | 98.5 | 94.8 |
| **a=0.01, r=0.5** | 301.9 | 174.1 | 344.4 | 183.2 | 340.8 | 191.5 |
| **a=0.01, r=1** | 359.2 | 323.8 | 396.4 | 378.7 | 382.3 | 361.1 |
| **a=0.01, r=2** | 366.3 | 370.3 | 401.6 | 406.4 | 397.1 | 392.0 |
| **a=0.5, r=0.5** | 303.9 | 168.5 | 342.8 | 167.5 | 343.3 | 168.6 |
| **a=0.5, r=1** | 367.5 | 325.1 | 390.8 | 371.0 | 375.9 | 363.9 |
| **a=0.5, r=2** | 366.8 | 365.9 | 406.8 | 400.2 | 393.3 | 384.1 |
| **a=1, r=0.5** | 303.0 | 155.1 | 332.6 | 133.3 | 331.6 | 124.2 |
| **a=1, r=1** | 360.5 | 324.7 | 392.3 | 364.9 | 375.7 | 362.8 |
| **a=1, r=2** | 372.5 | 368.0 | 404.4 | 401.7 | 384.1 | 390.8 |

*Table 5 Average Time When Five Blue Losses Occur*

| | 1A | 1B | 2A | 2B | 3A | 3B |
|---|---|---|---|---|---|---|
| **Stephen** | 143.7 | 130.4 | 117.3 | 108.8 | 98.4 | 94.8 |
| **a=0.01, r=0.5** | 322.0 | 160.5 | 340.3 | 181.5 | 336.8 | 190.9 |
| **a=0.01, r=1** | 349.3 | 345.5 | 374.6 | 364.2 | 366.8 | 354.9 |
| **a=0.01, r=2** | 354.3 | 371.1 | 379.2 | 382.3 | 378.1 | 372.7 |
| **a=0.5, r=0.5** | 324.0 | 157.2 | 339.1 | 164.0 | 335.4 | 166.9 |
| **a=0.5, r=1** | 354.1 | 332.9 | 372.8 | 361.3 | 361.8 | 353.4 |
| **a=0.5, r=2** | 357.9 | 365.5 | 380.9 | 375.7 | 374.6 | 366.7 |
| **a=1, r=0.5** | 323.9 | 146.5 | 326.3 | 130.0 | 326.8 | 122.2 |
| **a=1, r=1** | 352.7 | 337.0 | 371.1 | 350.0 | 361.2 | 352.9 |
| **a=1, r=2** | 368.1 | 368.7 | 381.8 | 376.6 | 368.8 | 373.5 |

*Table 6 Percentages of Runs Where Blue Reached the Flag*

| | 1A | 1B | 2A | 2B | 3A | 3B |
|---|---|---|---|---|---|---|
| **Stephen** | 29.2% | 20.3% | 2.7% | 2.0% | 0.2% | 0.0% |
| **a=0.01, r=0.5** | 62.3% | 44.7% | 11.3% | 9.0% | 9.5% | 3.8% |
| **a=0.01, r=1** | 56.5% | 66.5% | 1.3% | 5.5% | 0.7% | 5.2% |
| **a=0.01, r=2** | 59.3% | 59.7% | 0.5% | 0.8% | 1.2% | 0.0% |
| **a=0.5, r=0.5** | 59.0% | 49.7% | 12.7% | 11.3% | 6.0% | 4.8% |
| **a=0.5, r=1** | 55.3% | 66.0% | 1.0% | 4.2% | 1.3% | 2.7% |
| **a=0.5, r=2** | 58.5% | 57.2% | 1.3% | 0.8% | 0.2% | 0.2% |
| **a=1, r=0.5** | 57.5% | 35.0% | 12.8% | 6.8% | 8.0% | 3.2% |
| **a=1, r=1** | 55.2% | 66.8% | 1.2% | 5.0% | 0.3% | 3.5% |
| **a=1, r=2** | 58.5% | 58.0% | 0.3% | 0.3% | 0.0% | 0.0% |

*Table 7 Percentages of Runs Where All Five Blue Agents Were Shot*

| | 1A | 1B | 2A | 2B | 3A | 3B |
|---|---|---|---|---|---|---|
| **Stephen** | 70.8% | 80.8% | 97.3% | 98.3% | 99.8% | 100.0% |
| **a=0.01, r=0.5** | 35.7% | 55.3% | 82.7% | 91.0% | 84.8% | 96.2% |
| **a=0.01, r=1** | 35.8% | 30.2% | 81.2% | 82.5% | 87.5% | 89.5% |
| **a=0.01, r=2** | 32.0% | 31.3% | 81.3% | 79.3% | 83.8% | 84.8% |
| **a=0.5, r=0.5** | 39.3% | 50.5% | 80.7% | 88.7% | 87.8% | 95.3% |
| **a=0.5, r=1** | 35.3% | 31.5% | 84.8% | 87.3% | 88.2% | 89.8% |
| **a=0.5, r=2** | 31.8% | 34.3% | 77.7% | 79.8% | 84.8% | 86.8% |
| **a=1, r=0.5** | 41.3% | 65.0% | 79.8% | 93.2% | 87.0% | 97.0% |
| **a=1, r=1** | 39.0% | 29.2% | 82.2% | 84.2% | 89.3% | 88.8% |
| **a=1, r=2** | 31.3% | 32.7% | 80.8% | 79.7% | 88.3% | 86.3% |

*Table 8 Percentage of Runs that Timed Out (reached 500 time steps)*

| | 1A | 1B | 2A | 2B | 3A | 3B |
|---|---|---|---|---|---|---|
| **Stephen** | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| **a=0.01, r=0.5** | 2.0% | 0.0% | 6.2% | 0.0% | 5.8% | 0.0% |
| **a=0.01, r=1** | 8.0% | 3.3% | 17.7% | 12.0% | 12.0% | 5.5% |
| **a=0.01, r=2** | 8.8% | 9.2% | 18.2% | 19.8% | 15.2% | 15.2% |
| **a=0.5, r=0.5** | 2.0% | 0.0% | 6.8% | 0.0% | 6.2% | 0.0% |
| **a=0.5, r=1** | 9.7% | 2.7% | 14.3% | 8.7% | 10.5% | 7.5% |
| **a=0.5, r=2** | 10.2% | 8.5% | 21.2% | 19.7% | 15.2% | 13.0% |
| **a=1, r=0.5** | 1.2% | 0.0% | 7.3% | 0.0% | 5.0% | 0.0% |
| **a=1, r=1** | 6.2% | 4.0% | 17.0% | 11.2% | 10.5% | 7.7% |
| **a=1, r=2** | 10.2% | 9.5% | 18.8% | 20.0% | 12.0% | 13.7% |

*Table 9 Average Number of Blue Casualties for Runs Where Blue Reached the Flag (where applicable)*

| | 1A | 1B | 2A | 2B | 3A | 3B |
|---|---|---|---|---|---|---|
| **Stephen** | 3.35 | 3.49 | 3.88 | 4.00 | 4.00 | N/A |
| **a=0.01, r=0.5** | 2.30 | 3.12 | 2.74 | 3.35 | 2.60 | 3.61 |
| **a=0.01, r=1** | 3.14 | 2.73 | 3.38 | 2.94 | 3.00 | 3.39 |
| **a=0.01, r=2** | 3.04 | 3.08 | 4.00 | 4.00 | 3.43 | N/A |
| **a=0.5, r=0.5** | 2.40 | 3.17 | 2.68 | 3.50 | 2.97 | 3.69 |
| **a=0.5, r=1** | 3.19 | 2.80 | 3.17 | 2.60 | 2.63 | 3.25 |
| **a=0.5, r=2** | 3.10 | 2.96 | 3.88 | 3.60 | 4.00 | 4.00 |
| **a=1, r=0.5** | 2.53 | 3.36 | 2.56 | 3.59 | 3.00 | 3.63 |
| **a=1, r=1** | 3.14 | 2.75 | 3.43 | 3.10 | 4.00 | 3.10 |
| **a=1, r=2** | 3.09 | 3.07 | 4.00 | 4.00 | N/A | N/A |

*Table 10 Average Numbers of Blue Casualties for All Runs*

| | 1A | 1B | 2A | 2B | 3A | 3B |
|---|---|---|---|---|---|---|
| **Stephen** | 4.52 | 4.69 | 4.97 | 4.98 | 5.00 | 5.00 |
| **a=0.01, r=0.5** | 3.29 | 4.16 | 4.68 | 4.85 | 4.70 | 4.95 |
| **a=0.01, r=1** | 3.86 | 3.45 | 4.76 | 4.75 | 4.85 | 4.86 |
| **a=0.01, r=2** | 3.72 | 3.72 | 4.78 | 4.75 | 4.82 | 4.83 |
| **a=0.5, r=0.5** | 3.45 | 4.09 | 4.63 | 4.83 | 4.81 | 4.94 |
| **a=0.5, r=1** | 3.88 | 3.52 | 4.82 | 4.80 | 4.86 | 4.88 |
| **a=0.5, r=2** | 3.76 | 3.72 | 4.74 | 4.74 | 4.83 | 4.85 |
| **a=1, r=0.5** | 3.57 | 4.43 | 4.61 | 4.90 | 4.79 | 4.96 |
| **a=1, r=1** | 3.90 | 3.44 | 4.77 | 4.79 | 4.88 | 4.85 |
| **a=1, r=2** | 3.75 | 3.77 | 4.77 | 4.76 | 4.87 | 4.85 |

*Table 11 Average Number of Blue Casualties for Runs that Timed Out (where applicable)*

| | **1A** | **1B** | **2A** | **2B** | **3A** | **3B** |
|---|---|---|---|---|---|---|
| **Stephen** | N/A | N/A | N/A | N/A | N/A | N/A |
| **a=0.01, r=0.5** | 3.67 | N/A | 3.92 | N/A | 3.83 | N/A |
| **a=0.01, r=1** | 3.75 | 3.70 | 3.74 | 3.88 | 3.86 | 3.97 |
| **a=0.01, r=2** | 3.72 | 3.53 | 3.83 | 3.80 | 3.90 | 3.85 |
| **a=0.5, r=0.5** | 4.00 | N/A | 3.85 | N/A | 3.89 | N/A |
| **a=0.5, r=1** | 3.74 | 3.88 | 3.88 | 3.85 | 3.92 | 4.00 |
| **a=0.5, r=2** | 3.69 | 3.65 | 3.84 | 3.75 | 3.89 | 3.86 |
| **a=1, r=0.5** | 3.71 | N/A | 3.91 | N/A | 3.97 | N/A |
| **a=1, r=1** | 3.81 | 3.63 | 3.77 | 3.94 | 3.92 | 3.93 |
| **a=1, r=2** | 3.74 | 3.70 | 3.79 | 3.83 | 3.92 | 3.89 |

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19. ABSTRACT

This paper examines two movement algorithm options available to the user in the MANA (Map Aware Non-Uniform Automata) agent based distillation. The default Stephen algorithm is compared with nine variations of the alternative Gill algorithm and tested over six different scenarios.